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Decreased Body Weight in Fetal Rats After Irradiation With 2450-MHz (CW) Microwaves

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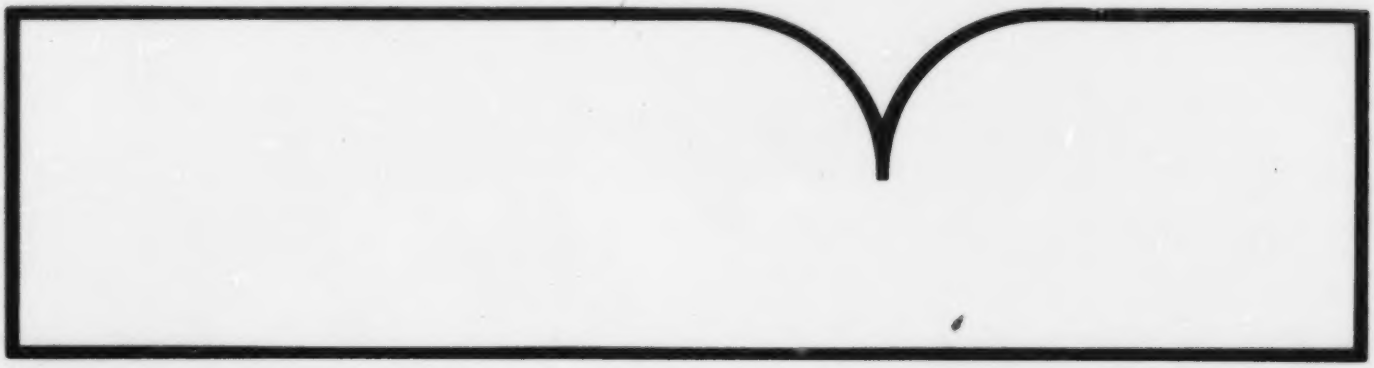

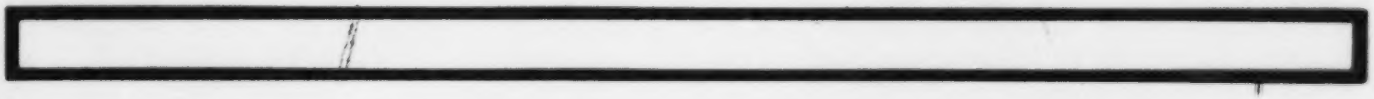

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16. ABSTRACT

Female Sprague-Dawley (CD) rats were exposed to 2450-MHz (CW) microwave radiation at incident power densities of 0 or 40 mW/cm2 (SAR = 6.0 W/kg) for 100 min daily on the sixth through 15th day of gestation. One-time exposure to the same conditions increased average colonic temperatures 2 C at the end of irradiation in pregnant rats of similiar size. There were 23 sham-irradiated and 24 microwave-irradiated females. When these groups were compared on the 21st day of gestation, no significant differences were found in pregnancy rates; in the numbers of live, dead or total fetuses; nor in the incidences of external visceral or skeletal anomalies or variations. However, mean fetal body weight was significantly (p=0.00008) lower after microwave irradiation and was 9% less than that of sham-irradiated litters.

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DECREASED BODY WEIGHT IN FETAL RATS AFTER IRRADIATION WITH 2450-MHz (CW) MICROWAVES

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Abstract—Female Sprague–Dawley (CD)† rats were exposed to 2450–MHz (CW) microwave radiation at incident power densities of 0 or 40 mW/cm^2 (SAR = 6.0 W/kg) for 100 min daily on the sixth through 15th day of gestation. One-time exposure to the same conditions increased average colonic temperatures 2°C at the end of irradiation in pregnant rats of similar size. There were 23 sham-irradiated and 24 microwave-irradiated females. When these groups were compared on the 21st day of gestation, no significant differences were found in pregnancy rates; in the numbers of live, dead or total fetuses; nor in the incidences of external, visceral or skeletal anomalies or variations. However, mean fetal body weight was significantly ($p = 0.0008$) lower after microwave irradiation and was 9% less than that of sham-irradiated litters. Sternal ossification was also significantly delayed in the microwave-irradiated fetuses ($p = 0.007$).It is concluded that even though a change in the malformation rate is not effected in rats, a fetotoxic effect does occur due to microwave-exposure conditions which raise maternal rectal temperatures to approx. 40°C and produce a specific absorption rate (SAR) ≥ 6 W/kg in the dam.

INTRODUCTION

THE AUTHORS previously reported their observations of lacking evidence in rats of fetotoxic or teratogenic potential of exposure to 2450-MHz microwaves at a power density of 28 mW/cm^2 [Be81) when the mean maternal colonic temperature was less than 40°C and the SAR = 4.2 W/kg. Similar exposure conditions during gestation in the mouse (Be78; Be82a) and Syrian hamster (Be82b) caused similar limited excursions of maternal temperature. Teratologic manifestations (increased incidence of anomalies or dead fetuses) were not evident in these studies, but fetotoxicity was seen in the form of decreased fetal body weight. This study was conducted to continue to examine the potential for fetotoxicity in the rat but at a SAR of 6.0 W/kg.

MATERIALS AND METHODS

Experimental methodology was identical to that previously reported (Be81), except that power densities used in this study were 0 or 40 mW/cm^2. The experimental methods are briefly described here. All the animals used in this study were CD (Sprague–Dawley) 90-day-old female rats. Groups of 16 virgin animals were time-bred by the supplier (the day that a copulatory plug was seen was considered Day 1) and were received in our animal facility on Day 3 of gestation. Three such groups were bred and received—one group per week—a total of 48 female rats. Each group of 16 was assigned randomly to subgroups of eight

†Charles River Breeding Labs, Inc., Wilmington, MA.

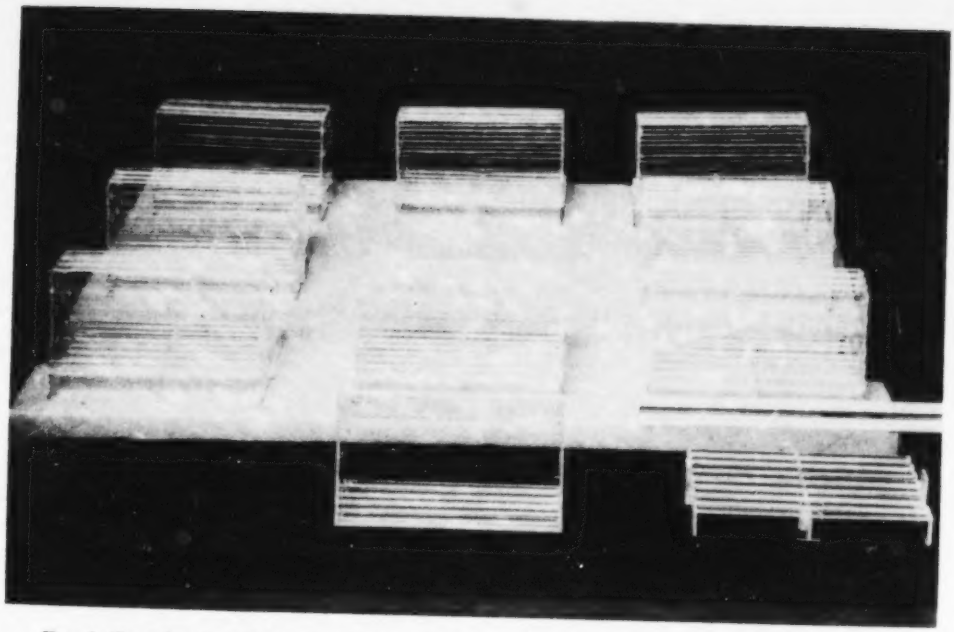

FIG. 1. Containers used for rats in this experiment and their positions in the microwave field. For display purposes, one additional cage is separated and placed at the lower border. The ruler measures in inches and is parallel to the *H*-vector.

microwave-irradiated and eight sham-irradiated rats. Treatment (microwave-irradiation at 40 mW/cm^2 or sham-irradiation) began on Day 6 of gestation and continued daily through Day 15. Each treatment was for 100 min and occurred between 1000 and 1500 hr.

On each day of treatment the animals were placed in individual acrylic plastic containers (18 cm long × 10 cm high × 11 cm base-width and 6 cm top-width) on foamed polystyrene trays† to catch body wastes (Fig. 1). The containers were positioned in an area 70 cm × 55 cm, with the long axes of the containers parallel to the *H*-field vector. The animals occupied the same position each day of treatment.

†Western Foam Pac, Inc., Greensboro, NC.

‡Lab Blox, Allied Mills, Inc., Fort Wayne, IN 46801.

Irradiation was conducted in a 2450-MHz (CW) anechoic facility (E175; B175). The incident power density was 40 mW/cm^2 applied to the dorsum of the subjects. Sham-irradiated subjects were treated concurrently and identically, but without radiation (power density = 0 mW/cm^2), in a chamber adjacent to the anechoic chamber. The air flow was common to both groups of animals, was recirculated and its temperature was 22.2 ± 1°C, relative humidity 50 ± 5%, and velocity 0.08–0.1 m/sec. Other than periods of treatment, the subjects were maintained in shoe-box type cages in which feed‡ and water were available *ad libitum*.

On the 21st day of gestation, each female was killed, its uterus exposed and examined for pregnancy, and the numbers of live, dead and resorbed conceptuses tallied. Each live fetus was blotted dry, examined for external morphology, weighed and fixed either in Bouin's fixative or in ethyl alcohol (every third living fetus). At a later

date, razor-sections were made of the head, and the abdomen and thorax were incised ventrally to allow examination of internal morphology of the Bouin's-fixed fetuses. Alcohol-fixed fetuses were cleared for skeletal visualization (KOH-Alizarin) and examined under 15 × magnification for morphology of ossified sternebrae.

Frequency-type data (pregnancy and anomaly rates) were expressed as litter units and were analyzed by experimental treatment using chi-square. Continuous data (numbers of live, dead and resorbed, and total fetuses, live fetal weight, and ossified sternebrae numbers) were expressed as the mean of the litter and each analyzed using analysis of variance in a computer-based statistical package called General Linear Models Regression Procedure (He79). In the cases of the two experimental variables that were statistically significant (fetal body weight and ossified sternebrae centers), the analytic methods included adjustments for the number alive in each litter. The parameters of these analyses are in Table 1. The level of significance was set at $p < 0.05$ for all statistical tests.

To determine the thermal load imparted by this exposure, colonic temperatures of eight pregnant rats were measured immediately before and after irradiation at 40 mW/cm^2 for 100 min. Body weights were similar to those of the main study in early gestation. Temperatures were determined with a digital electronic thermometer using a thermistor probe.

SAR is estimated from Durney *et al.* (Du78, p. 96) to be 0.15 W/kg per unit power density.

RESULTS

Pregnancy rates, and numbers of live, dead or resorbed, as well as total fetuses per litter were similar in sham-irradiated and microwave-irradiated groups (Table 1). The body weights of live fetuses were significantly decreased ($p = 0.0008$) in the microwave-irradiated group, and was 9% less than the sham-irradiated group. The number of ossified sternal centers were also significantly decreased ($p = 0.007$) in the litters irradiated at a power density of 40 mW/cm^2. The incidence of litters with anomalous fetuses was similar in both groups; three of 20 sham-irradiated and five of 22 microwave-irradiated litters contained at least one anomalous live fetus.

The mean colonic temperature of eight pregnant rats increased 2.0°C after a single exposure to a power density of 40 mW/cm^2 for 100 min. Their mean temperatures before and after irradiation were 37.6 ± 0.5 and 39.6 ± 0.5°C, respectively.

Table 1. Results of exposure of CD rats to 2450-MHz (CW) microwaves for 100 min daily, Days 6–15 of pregnancy. Values are means of litter means ± S.D.

Power density (mW/cm^2)	0	40
Bred animals, No.	23	24
Pregnancies, No.	20	22
% Pregnant	87	92
Live fetuses/litter	11.7±1.3	11.0±2.4
Dead and resorbed fetuses/litter	1.0±0.8	0.7±0.9
Total implants/litter	12.7±1.4	11.8±2.4
Live fetal weight (g)	3.40±0.22	3.14±0.22*
Ossified sternal centers/litter	5.4±0.6	4.8±0.6**

* F=13.38; df=1,39; p=.0008

**F=8.00; df=1,39; p=.007

None of the rats died during this study. One rat in the sham-irradiated group was excluded from the study because of a skin lesion. On the 21st day of presumed gestation, mean body weights of non-pregnant mated rats were similar in both groups (sham-irradiated: mean = 255 g, S.D. = 2.5, N = 3; microwave-irradiated: mean = 265 g, S.D. = 9.9, N = 2).

DISCUSSION

In an earlier study (Be81), the potential which 2450-MHz microwaves may have to alter the rat fetus was examined. In that study, acute deaths occurred in three of eight bred rats during the first irradiation. The conditions of exposure used in that situation were the same as in this report—40 mW/cm^2. Now considered inexplicable, the acute deaths were thought to have been directly caused by only lethal hyperthermia. Further thought has encouraged re-examination of bred rats exposed to 40 mW/cm^2 in an attempt to induce fetal changes, especially as the earlier study of 0 and 28 mW/cm^2 (Be81) reported the absence of fetal effects.

The study reported here shows no evidence of teratogenesis as a result of exposure to 2450 MHz (CW), 40 mW/cm^2 for 100 min daily during organogenesis and the fetal stage. No shifts occurred in most of the conventional parameters of teratologic studies; rates of pregnancy and numbers of living and dead conceptuses in sham- and microwave-irradiated groups were similar. The rates of litters which contained anomalous fetuses were also similar in both groups. However, mean fetal body weight was reduced by 9% in the microwave-irradiated group. The mean number of ossified sternebrae was also decreased in the microwave-irradiated fetuses.

Some evidence exists in this study to show that the fetal growth retardation was not secondary to toxicity induced in the dam by microwave-irradiation. Three sham-irradiated and two microwave-irradiated mated dams had no signs of implantation when they were killed on the 21st day of presumed gestation. No statistical difference was seen in their body weights on that day. A decrease in the weights of the microwave-irradiated rats would lead one to suspect toxicity.

Wilson (Wi73) has argued that increased dosage of an insult toxic to the fetus produces an increased degree of response where the "... type of response may change from growth retardation to malformation...". If this holds true for radio-frequency radiation (RFR), as it appears to hold true for ionizing radiation and possibly other fetal insults, then some level of RFR might cause growth retardation without a concommitant increase of terata or lethality incidences. This study demonstrates just this effect. Of the conventional variables that measure the range of embryotoxicity (death, terata, body weight), all were employed here. However, only growth retardation, in the form of decreased fetal body weight, was observed in the litters exposed to 40 mW/cm^2. Though the decrease in the mean was only 9%, the groups had very significantly different body weights. Confirmation that the microwave-irradiated fetuses were generally retarded in development is given by the demonstration of younger skeletons (fewer ossified sternal centers) in this group.

These results are similar to those of studies in the literature which do not report morphologic teratogenesis due to exposure to RFR during gestation when maternal body temperatures remain less than 41°C. For instance, Dietzel (Di72; Di75) saw no increase in the rate of tail or extremity abnormalities of rat fetuses when RFR conditions produced a mean colonic temperature < 41°C in the dam. Chernovetz (Ch75) also found no significant alterations in rat fetuses exposed to 2450-MHz microwaves when the mean colonic temperature of dams rose to 40.6°C.

Laskey (La70) also observed decreased body weight in fetal rats exposed to RFR, without increased incidences of anomalous or dead fetuses. In this study, maternal colonic temperature was raised by the radiation (2450 MHz, 100 mW/cm^2) to 42.5°C. That no terata or lethality was caused by this high SAR (estimate = 15 W/kg) is likely due to the short (8–13 min), one-time exposure.

A summary of available pertinent reports of the effects of RFR in fetal rats is in Table 2. The table is ordered by SAR. This ordering suggests a possible "threshold" for effects in the fetus, the most consistent effect being decreased fetal body weight. The break from a no-effect level of

Table 2. Summary of observed effects in rat fetuses exposed to RFR. *Data are arranged by* SAR. GD = *exposed during days of gestation. Fetal effects seen:* ↑ = *increased,* ↓ = *decreased,* S = *statistically significant,* NS = *not statistically significant.* *SAR *from reference or from Du*78

Exposure Conditions	Exposure Duration(s)	SAR* (W/kg)	Dam's Rectal Temp. (°C)	Fetal Effects Seen			Reference
				Lethality	Anomalies	Body Weight	
915 MHz; 10mW/cm^2	6h/d during gestation	3.6	37.5	NS	NS	NS	Je82
2450 MHz; 28mw/cm^2	GD 6-15; 100 min/d	4.2	40.3	NS	NS	NS	Be81
6000 MHz; 35mW/cm^2	102h during gestation	5.3	"normal"	NS	NS	NS	Je79
2450 MHz; 40mW/cm^2	GD 6-15; 100 min/d	6.0	39.6	NS	NS	+S	This report
27.12 MHz; 55A/m	GD 1-15(odd days); 20-40 min	11-12.5	43	+S	+S	+S	La82
2450 MHz; 100mW/cm^2	GD 8 or 13; 8-13 min	15	42.5	NS	NS	+S	La70
2450 MHz;	GD 10-16; 20 min	31	--	+S	NS	+S	Ch77

SAR to one which causes a significant decrease in fetal weight is at approx. 6.0 W/kg. The effects listed in this table can also be associated with rises in maternal colonic temperature. Maternal colonic temperature, as a measure of threshold, would be approx. 40°C for decreased fetal weight and somewhat higher temperature for more severe effects of terata and lethality. Not included in these views are any differences in sensitivity due to the age of the conceptus, or to the length or repetition of exposure; the data base for these judgments are not yet available.

In summary, it appears that exposure to RFR during gestation can induce decreased fetal body weight (fetotoxicity) without also causing increased terata or death (embryotoxicity). When these parameters of harm to the developing organism are examined as two levels of response to absorbed RFR, fetotoxicity appears at lower SARs and maternal temperatures than embryotoxicity, and often without any increase in lethality or terata. Therefore, body weight may be a better variable with which to delineate a threshold of detrimental fetal response to RFR. Without a broader data base that includes length and repetition of exposure, a combination of SAR and maternal rectal temperature appears to be an appropriate scale for threshold of fetotoxicity.

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